Fermi National Accelerator Laboratory

FERMILAB-Pub-83/48-THY
May, 1983

Testing Lorentz Invariance in Baryon Decay

R. HUERTA*
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

and

J.L. Lucio M.
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510
and
Centro de Investigacion y Estudios Avanzados I.P.N.
Apdo. Postal 14-740; Mexico D.F. 07000 Mexico

ABSTRACT

We show that, in contrast with μ decay, measurements of the baryon lifetime and semileptonic branching ratio at different energies lead to a test of Lorentz invariance.

*Address after June 1st: Dept. de Fisica, CINVESTAV Apdo Post. 14-740 Mexico D.F. 07000, Mexico

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

Recently Nielsen and Picek [1] proposed a way of introducing Lorentz noninvariant interactions (LNI) in gauge theories. Using the extended (to include LNI) standard model [2] the authors of Ref. 1 showed that μ decay is almost insensitive to the LNI[F1] and therefore the existing tests of Lorentz invariance based on measurements of muon lifetime in flight are not very reliable. In the other hand meson decays are sensitive to LNI and have been considered by Nielsen and Picek as the most promising place to test Lorentz invariance.

In this letter we report on the influence of LNI in baryon decay. The relevance of such alternative for typical Fermilab energies has been the motivation for this research.

Following Nielsen and Picek [1] we start with the effective Hamiltonian

$$H_{eff} = \frac{G}{\sqrt{2}} (g^{\mu\nu}+X^{\mu\nu})(J_\mu^+(x)J_\nu(x)+h.c) \qquad (1)$$

where

$$X^{\mu\nu} = 0 \text{ if } \mu \neq \nu, \quad X^{00} = \alpha, \quad X^{ii} = \frac{\alpha}{3} \qquad (2)$$

and so α characterize the strength of the LNI.

Let us now consider two different decay modes

a) <u>Semileptonic Baryon Decay $B \to B'\ell\bar{\nu}_e$</u>. In this case we write for the hadronic current

$$\langle B'|J_\mu|B\rangle = \bar{U}_{B'}(g_V+g_A\gamma 5)\Gamma_\mu U_B . \tag{3}$$

We could consider a more general expression in Eq. 3, however this will not modify our basic conclusions.[F2] Using Eqs. (1-3) it is straightforward to derive the modification of the partial decay rate due to the LNI[F3]

$$\Delta W_{LNI} = \frac{G^2}{72\pi^3}\,\frac{\alpha}{\gamma}\,(\gamma^2-\tfrac{1}{4})\,(g_V^2-g_A^2)m_B^5\, I_0 \tag{4a}$$

$$I_0 = \xi\left[(1-\xi^4)-\frac{2}{3}(1-\xi^2)^3+\frac{1}{6}(1-\xi^4)(1-\xi^2)^2+4\xi^2\log\xi\right] \tag{4b}$$

with α defined in Eq. (2), $\gamma=E_B/m_B$ and $\xi=m_{B'}/m_B$. It is clear that ΔW_{LNI} vanishes if $|g_V|=|g_A|$ independently of $m_{B'}$. In the other hand if $|g_V|\neq|g_A|$ then ΔW_{LNI} only vanishes if $m_{B'}=0$. Therefore we conclude that the selection rule [1] stating that the decay rate for μ type decays is not sensitive to LNI is only valid if $|g_V|\neq|g_A|$ or if it is possible to neglect the masses of the particles in the final state.

An approximated expression for the modified standard partial decay rate W_0 [3], due to the LNI, is obtained by expanding in powers of $\delta=\Delta/\Sigma$ where $\Delta=m_B-m_{B'}$ and $\Sigma=m_B+m_{B'}$

$$W = \frac{W_0}{\gamma}\left[1 + C_1\alpha\left(\gamma^2 - \frac{1}{4}\right)\right] + 0(\delta^2)$$

$$W_0 = \frac{G^2}{60\pi^3}\,\Delta^5\left(\frac{\Sigma}{2m_B}\right)^3\,(g_V^2+3g_A^2) \tag{5}$$

$$C_1 = \frac{8}{3}\,\frac{g_V^2-g_A^2}{g_V^2+3g_A^2}\ . \tag{6}$$

The importance of the LNI term depends both on the value of α and the energies at which the experiment is done.

b) <u>Weak Non-leptonic Decays $B\to B'\pi$</u> The first step in describing weak nonleptonic decays is to incorporate the strong interaction corrections into the weak Hamiltonian Eq. (1). Using the standard procedure [5] we get[F4]

$$H'_{eff} = -\frac{G_F}{\sqrt{2}}\sum_{k=1}^{2}\,(a_k g_{\mu\nu}+b_k X_{\mu\nu})\ 0_k^{\mu\nu} \tag{7}$$

where

$$0'_{\mu\nu} = \frac{1}{3}\,\bar{d}\gamma_\mu(1-\gamma_5)u\bar{u}\gamma_\nu(1-\gamma_5)s-\bar{d}\,\frac{\lambda a}{2}\,\gamma_\mu(1-\gamma_5)u\bar{u}\,\frac{\lambda a}{2}\,\gamma_\nu(1-\gamma_5)\ s$$

$$0^2_{\mu\nu} = \frac{2}{3}\,\bar{d}\gamma_\mu(1-\gamma_5)u\bar{u}\gamma_\nu(1-\gamma_5)s+\bar{d}\,\frac{\lambda a}{2}\,\gamma_\mu(1-\gamma_5)u\bar{u}\,\frac{\lambda a}{2}\,\gamma_\nu(1-\gamma_5)\ s$$

$$a_k = [\alpha_s(M^2)/\alpha_s(\mu^2)]^{d_k},\ b_k = [\alpha_s(M^2)/\alpha_s(\mu^2)]^{d_k} \text{ with } d_1 = -4/7$$

$$d_2 = 2/7,\ d'_1 = 4/21,\ \ d'_2 = -\,2/21, \tag{8}$$

The second step is the evaluation of the matrix elements of this Hamiltonian. In the case of S wave parity violating process there are two main contributions:
1) Factorization term which can be written

$$<B'\pi|H_{eff}|B> \simeq -\frac{G_F}{\sqrt{2}}\sum_k (a_k g_{\mu\nu}+b_k x_{\mu\nu})<B'|J^\mu|B><\pi|J^\nu|0> \quad (9)$$

2) soft pion contribution. In this case the matrix element $<B'\pi|H'_{eff}|B>$ can be expressed in terms of the matrix elements of the effective Hamiltonian between baryonic states

$$<B'\pi|H_{eff}|B> \sim <B'|0^k_{\mu\nu}|B> (a_k J^{\mu\nu}+b_k x^{\mu\nu}). \quad (10)$$

Instead of considering a particular model to evaluate the right hand part of Eq. (10) we parametrize the partial width in a similar fashion as the obtained in the semileptonic case

$$W(B\to B'\pi) = W^0(B\to B'\pi)\ [1 + c_2\alpha(\gamma^2-1/4)]. \quad (11)$$

It is clear that Eq. (9) gives a non-vanishing contribution to c_2 in Eq. (11). So in writing Eq. (11) we assume that the soft pion term gives a similar result. It is worth noticing that although the contribution proportional to $g^{\mu\nu}$

in Eq. (10), when evaluated in the bag model, is of opposite sign that the similar term in Eq. (9) the latter represents only 15 to 20% of the total amplitude [4] and therefore we expect $c_2 \neq 0$.

Let us now consider the possibility of measuring the LNI effects above discussed in the lifetime and semileptonic branching ratio. For the sake of definiteness we will consider Σ^- decay. The lifetime is dominated by the nonleptonic decay $\Sigma^- \to n\pi^-$. Therefore comparing the results obtained at high energy with those at low energy it is possible to set a limit on $c_2\alpha$

$$\frac{\tau^0}{\gamma^0}\left(\frac{\gamma^1}{\tau^1} - \frac{\gamma^0}{\tau^0}\right) \simeq c_2 \ \alpha \ \gamma_1^2 \tag{12}$$

on the other hand measurements of the semileptonic branching ratio $B = W(B \to B' \ell \bar{\nu}_e)/W(B \to \text{all})$ restrict

$$\frac{B_1 - B_0}{B_0} = (c_2 - c_1) \ \alpha \ \gamma_1^2 B_0 . \tag{13}$$

The Fermilab charged hyperon beam will run at energies around 300 GeV. It is reasonable to expect measurements of the lifetime and semileptonic branching ratio to about 5% [7]. This will imply a limit on $\alpha \sim 10^{-5}$ to 10^{-7}.[F5]

In conclusion we have shown that the semileptonic baryon decay is sensitive to the LNI. In the other hand we have argued that nonleptonic baryon decay will also be sensitive to the LNI but we are unable to make a definite prediction for c_2 (see Eq. 11). The consequence of this is that either the semileptonic branching ratio and/or the baryon lifetime as measured at high energies could be different from the values obtained at low energies. Considering typical Fermilab energies and assuming that the measurements are done to about 5% we obtain the limits $\alpha \sim 10^{-5}$, 10^{-7} from the branching ratio and lifetime respectively. This is an improvement of two to three orders of magnitude on the existing limits [1,8][F6] on the LNI.

We wish to thank J.D. Bjorken for calling our attention to this problem; J. Lach for useful conversations and the Theory Group at Fermilab for its warm hospitality.

FOOTNOTES

F1 Terms of order $(m_e/m_\mu)^2$ as well as $O(\alpha^2)$ have been neglected in [1].

F2 The contribution of the remaining form factors only modify the $O(\delta^2)$ terms. See Eq. (5).

F3 In this Eq. we have neglected the masses of the leptons in the final state as well as terms of order $\alpha^2(\gamma^2-1/4)$.

F4 We are neglecting SU(4) symmetry breaking. A study of such effects as well as the evaluation of the matrix elements in the K_0-$\bar{K}_0$ system is given in [6].

F5 We are assuming $c_2 \sim 1$. This is not unreasonable. Furthermore as we increase c_2 we obtain a smaller value for α.

F6 There exist data on the K_0-$\bar{K}_0$ that could be interpreted as evidence of LNI [9]. Analysis based only on the energy dependence of Δm_k, gives the limit $\alpha \lesssim 3\times10^{-6}$ [1,6].

REFERENCES

[1] N.B. Nielsen and I. Picek, Phys. Lett 114B (1982) 141;
H.B. Nielsen and I. Picek, Nucl. Phys. B211 (1983) 269.

[2] S.L. Glashow, Nucl. Phys. 22, (1969) 571;
S. Weinberg, Phys. Rev. Lett. 19 (1967) 1264;
A. Salam in "Elementary Particle Theory" eds. Svartholm, Amquist and Widsells 1968.

[3] H. Pietschmann "Formulae and Results in Weak Interactions" Spinger-Verlag, New York, 1974.

[4] J.F. Donoghue et al., Phys. Rev. D21 (1980) 186;
A. Galic, D. Tadic and J. Trampetic, Nucl. Phys. B158 (1979) 300.

[5] M.K. Gaillard, B.W. Lee, Phys. Rev. Lett. 33 (1974) 108;
L. Marani, G. Altarelli, Phys. Lett 59B (1975) 293;
M.A. Shifman, A.I. Vanishtein and V.I. Zakharov; JETP (Sov. Phys.) 45 (1977) 670.

[6] J.L. Lucio M. and W.A. Ponce, in preparation.

[7] J. Lach, private communication.

[8] R. Huerta and J.L. Lucio M., Fermilab-Pub-83/18-THY, (1983).

[9] S.H. Ahronson et al., Phys. Rev. Lett 48 (1982) 1306.